

**CLUSTER-INDUCED FLUCTUATIONS IN THE MICROWAVE
BACKGROUND RADIATION**

NASA Grant NAGW-3825

Final Report

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Principal Investigator
Dr. Mark Birkinshaw

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Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

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The research proposed under NAGW-3825 was

- to detect, map, and interpret the Sunyaev-Zel'dovich (SZ) effects in two samples of distant clusters of galaxies with the OVRO 40-m telescope: an optically-selected sample of 26 clusters at the North Ecliptic Pole, and an X-ray selected sample of clusters based on the Einstein Medium Sensitivity Survey
- to make small maps of the strongest cluster SZ effects using the OVRO 40-m telescope
- to combine the SZ and X-ray data for well-detected clusters to determine the value of the Hubble constant and set limits to the value of the deceleration parameter, and
- to study the properties of cluster atmospheres using the SZ effect.

The target sensitivity for this work was 30 microK at each point observed by the 40-m telescope. This was expected to be achievable in about four weeks of good weather in each observing season during the tenure of the grant, and also needed deep radio data on the target clusters to ensure that radio source confusion was not compromising the quality of the SZ effect data.

These original aims were slightly modified as the research proceeded. The complete NEP sample of clusters was observed, as desired, but the ultimate sensitivity was only about 50 microK per cluster. The increased noise over the original aim was due to the need to observe with a more complicated switching scheme to reduce systematic errors to a level of less than 100 microK, where they could not cause problems with the detection of the stronger SZ effects, plus difficulties with weather and radio interference. Only parts of the second cluster sample were observed because of the increased time dedicated to finishing the NEP sample, but a new X-ray selected sample of clusters (the XBACS sample) was defined during this period, and all clusters in that sample available to the 40-m telescope were observed during the 1996/7 season.

The increased time required to achieve good sensitivity, and the rapid improvement in interferometric mapping of cluster SZ effects, rendered the second aim of this research pointless: better measurements of SZ effect structures can now be obtained either using interferometers, or using bolometer arrays such as SuZIE. No further work on single-dish mapping was attempted, therefore.

The interpretation of SZ effects in terms of cluster properties and the cosmological parameters proceeded as expected (and is described in detail in a long review article; Birkinshaw 1997).

The detailed results of the research are given below.

- Extensive data were taken on the SZ effect with the OVRO 40-m telescope equipped with its new receiver in each of the winter observing seasons. These have now been analyzed, and several new SZ effects have been identified (e.g., in Abell 586, 1722, 2232, 2240, 2255, and 2317) while observations of clusters with known SZ effects (e.g., in CL 0016+16, Abell 665, and 773) provide cross-checks with earlier data.
- Long observations of a reference blank sky region provide excellent checks on the statistical properties of the data, and confirm the absence of detectable systematic errors at the level of the primordial CMB anisotropy on 7 arcmin angular scales.

- The quasar pair PC1643+4631A and B does not show any detectable SZ effect, contrary to the claims of Jones et al. (1997; ApJ 479 L1), at a level substantially below that reported in their paper. This removes the difficulty of explaining the reported CMB structure: a difficulty that was leading to extreme models in theoretical literature. Work with the Cambridge group that reported the SZ effect continues, to understand the origin of the signal that they reported.
- The most luminous X-ray cluster (RX J1347.5-1145; Schindler et al. 1997, A&A 317 646) was observed to contain a strong and previously-uncatalogued radio source, which makes it impossible to obtain useful SZ effect data at microwave frequencies. Detection of the SZ effect should be possible using mm- and sub-mm systems such as SuZIE.
- The most luminous cluster radio halo source yet detected was found in the hottest-known X-ray cluster, Abell 2163 (Arnaud et al 1992; ApJ 390 345), where it interferes slightly with SZ effect observations, but suggests a relationship between electron pressure and the persistence of cluster radio halos which I have commented on before. This halo source was the subject of an AAS press release (Herbig and Birkinshaw 1995). The cluster also contains an unusually variable inverted-spectrum source, which may still be strong at mm waves.
- A paper on the value of the Hubble constant deduced from X-ray and SZ effect measurements of Abell 2218 was published (Birkinshaw and Hughes 1994), and a paper on the value of the Hubble constant based on the analysis of CL 0016+16 is in final preparation (Hughes and Birkinshaw, see Hughes and Birkinshaw 1996). The work on CL 0016+16 required an extensive redevelopment of our modeling techniques to take account of non-spherical cluster gas distributions. We are expecting to repeat our earlier work on Abell 665 and 2218 using these new techniques and improved ROSAT (and AXAF) data.
- A compilation of cluster distances from the SZ/X-ray technique was used to produce a cluster Hubble diagram, from which a value of the Hubble constant of about 60 km/s/Mpc can be deduced. There are insufficient points to allow useful determinations of the deceleration parameter at present (Birkinshaw 1997). Suspicions of systematic errors in the X-ray and SZ effect calibrations, and the possibility of orientation-dependent biases, will be removed when further clusters (including those from the samples studied in this work) are added to the diagram.
- Studies of 0016+16 led to the serendipitous detection of several companion clusters, now confirmed spectroscopically (Hughes et al 1996; Hughes and Birkinshaw 1997). These may be examples of the objects responsible for features in the cross-correlation spectrum of clusters and extended X-ray sources (Hughes and Birkinshaw 1997)
- Based on this work, a feasibility study led to the selection of a sample of clusters to be observed with the AXAF satellite under guaranteed time, with the aim of producing a high-quality cluster-based Hubble diagram capable of measuring the Hubble constant to 10 per cent or better.

- Techniques for catalog cross-correlation were developed which can help to associate catalogues radio sources with SZ cluster candidates (Nguyen et al. 1997).

Publications

The following publications were based wholly, or in part, on work performed with the aid of this grant.

- Birkinshaw, M., 1997. Physics Reports, in press. 'The Sunyaev-Zel'dovich Effect',
- Birkinshaw, M., Gull, S.F., Hardebeck, H.E., and Moffet, A.T., 1997. ApJ, submitted. 'The structures of the Sunyaev-Zel'dovich effects towards three clusters of galaxies'.
- Birkinshaw, M. and Hughes, J.P., 1994. ApJ, 420, 33. 'Abell 2218 and the Hubble constant'.
- Birkinshaw, M. and Hughes, J.P., 1997. In "Particle Physics and the Early Universe", eds Bately, R., Jones, M.E. and Green, D.A., (<http://www.mrao.cam.ac.uk/ppeuc/proceedings>). 'CL 0016+16 and the Hubble Constant'.
- Herbig, T. and Birkinshaw, M., 1995. Bull.AAS, 26, 1403. 'Discovery of a Radio Halo Source in Abell 2163'.
- Hughes, J.P. and Birkinshaw, M., 1994. In "The Soft X-ray Cosmos", p.378; eds. Schlegel, E.M., Petre, R.; American Institute of Physics Press, New York. 'Complex spatial structures of the Sunyaev-Zel'dovich decrement clusters Abell 665 and CL 0061+16'.
- Hughes, J.P. and Birkinshaw, M., 1996. Bull.AAS, 27, 1292. 'The distance to CL0016+16 and the Hubble constant'.
- Hughes, J.P., Birkinshaw, M., and Huchra, J.P., 1995. ApJ, 448, L93. 'A new X-ray discovered cluster of galaxies associated with CL0016+16'.
- Hughes, J.P., Birkinshaw, M., and Huchra, J.P., 1995. Bull.AAS, 26, 1429. 'A New X-ray-discovered Cluster of Galaxies Associated with CL0016+16'.
- Hughes, J.P. and Birkinshaw, M., 1997. ApJ, submitted. 'Another X-ray-Discovered poor cluster of galaxies associated with CL 0016+16'.
- Nguyen, D., DuPrie, K., and Zografou, P., 1997. ADASS-7, in press. 'A multidimensional binary search tree for catalog correlations'.

